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Seismic Risk Analysis of Industrial Concrete Structures: A Case Study of an Old Reinforced Concrete Building with Shear Wall

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ABSTRACT

Iran's industrial growth in the 1960s and 1970s was accompanied by the development of industrial facilities that often lacked comprehensive seismic codes at that time. This study presents a seismic risk analysis for a two-story concrete building with shear wall that constructed during this period. Seismic hazard analysis was conducted using both probabilistic and deterministic approaches, employing spectral models and validated attenuation relationships. Subsequently, vulnerability assessment, debris volume, and potential casualties from earthquakes at various intensity levels were determined using fragility curves based on the HAZUS methodology. The results indicate that during severe earthquakes, the probability of damage is very high, with debris volume ranging from 8 to 118 tons, although this debris would not block surrounding pathways. Casualty estimates for different earthquakes vary from less than one to 8 fatalities. While this building is weaker compared to contemporary structures, it demonstrates acceptable performance. This study highlights the importance of considering seismic risk and post-earthquake crisis management in old industrial buildings.

Keywords: Seismic hazard analysis; reinforced concrete shear wall; seismic vulnerability; exposure; debris

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1. INTRODUCTION

Between 1963 and 1974 Iran underwent major structural transformations in its economy that profoundly influenced the nation's industrial development. During these years, reforms in the agricultural sector disrupted traditional production

systems, resulting in a mass migration of rural laborers to urban centers. This young and available workforce provided a cheap and efficient labor base that contributed significantly to emerging assembly industries and large-scale manufacturing.

Simultaneously, the rise in oil prices and the expansion of oil extraction and exports became the principal source of funding for extensive industrial investments. The injection of substantial financial resources made possible the rapid development of heavy industries and major infrastructure projects.

Between 1968 and 1973, the share of the industrial and mining sectors in the national income grew considerably, rising from approximately 480 billion rials to 22%. This industrial expansion led to the emergence and growth of heavy and infrastructural industries, including the Esfahan Steel Complex, machinery and aluminum plants in Arak, the machine manufacturing and tractor production industries in Tabriz, and several industrial complexes along the northern coast of the Persian Gulf. These projects were typically implemented with the participation and investment of Western countries and corporations, which played a crucial role in accelerating Iran's industrialization process [1].

This period is regarded as one of the key phases in Iran's economic transformation due to its industrial boom and significant capital investments, which laid the groundwork for sustained growth in subsequent decades. Concurrently, rural migrants actively participated in urban industries, particularly in assembly-line production, thereby contributing to the manufacturing of domestic industrial goods. The economic growth fueled by oil revenues enhanced the government's capacity to invest in infrastructure and heavy industry, shaping the foundation of Iran's industrialization in a profound and enduring manner. Following the devastating earthquake on September 1, 1962 (10 Shahrivar 1341), which struck the Boein Zahra region with a magnitude of 7.2 and caused approximately 12,000 fatalities, Iran drafted its first seismic code. As a consequence, in 1964, the Plan and Budget Organization published a report titled "Provisional Code for the Protection of Buildings Against Earthquakes." Subsequently, in September 1967, the Office of Building Studies and Standards within the Ministry of Housing formed a committee that issued the "Building Safety Code Against Earthquakes." This code consisted of two chapters: the first addressed masonry structures, while the second presented guidelines for evaluating the

seismic resistance of buildings. According to this document, only structures exceeding three stories or 11 meters in height, with steel or reinforced concrete frames, were permitted. In 1969, the code became a mandatory directive published by the Plan and Budget Organization, and it was gradually revised and expanded over time.

The first official edition of the code, titled "Code for the Design of Buildings Against Earthquake," was released in 1987 as Iranian Standard No. 2800, developed in collaboration with the Institute of Standards and Industrial Research of Iran. After approval by the Council of Ministers in 1988, it was mandated for implementation across governmental and municipal agencies. Following the catastrophic Rudbar and Manjil earthquakes in 1990, awareness of the necessity to enforce this standard increased significantly [2].

This progressive process of developing seismic design codes in Iran represents a milestone in the advancement of earthquake-resistant structural design, initiated after the Boein Zahra earthquake and subsequently refined into more comprehensive and specialized standards.

Therefore, prior to the 1980s, Iran's seismic codes had little practical influence on structural design and construction practices. Moreover, most industrial buildings from the studied period were designed and built by foreign companies and specialists, making it unlikely that Iranian seismic regulations were considered in their design.

In this paper, the seismic risk of a reinforced concrete-framed industrial office building, designed and constructed by a foreign contractor in 1971, is evaluated. To this end, site-specific seismic hazard analyses were conducted using both deterministic and probabilistic methods, followed by seismic vulnerability assessment using appropriate fragility curves to estimate building performance under different earthquake intensity levels — including deterministic, minor, design-level, and severe events. Based on the vulnerability and damage analysis results, the potential debris volume and casualty estimates were obtained using the HAZUS methodology.

2. METHODOLOGY

2.1. Seismic Hazard Analysis

The studied building is a two-story structure located at coordinates $30^{\circ}45'40''$ N and $49^{\circ}58'47''$ E. The building has a reinforced concrete frame, with a total floor area of 1,400 square meters and a height of 7 meters. Constructed in 1971, it is classified as having a low level of compliance with modern seismic

design codes. The building is considered to be regular in plan and elevation, and the effects of infill walls on structural behavior have been neglected. The building's location is shown in [Figure 1](#). As illustrated, four active faults are situated at relatively short distances from the site.

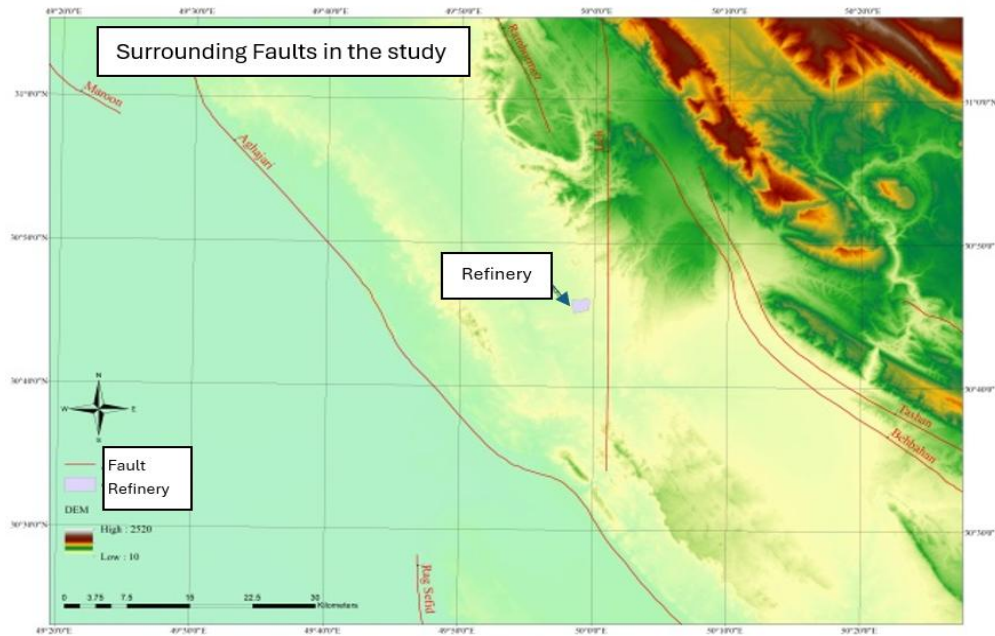


Figure 1. Site location, topographic conditions, and surrounding faults in the study area.

The uniform hazard spectra for severe, design, and minor earthquakes at the administrative building site are presented in [Figure 2](#). The analysis was performed using the OpenQuake software and ground-motion prediction equations (GMPEs) developed by Ghasemi et al. (2009), Chiou and

Youngs (2008), Zhao et al. (2006), Akkar and Cagnan (2010), and Akkar et al. (2014) [3-7]. As illustrated, the spectral acceleration values reach up to 1.8 g for severe earthquakes, 1.0 g for design-level earthquakes, and 0.1 g for minor earthquakes.

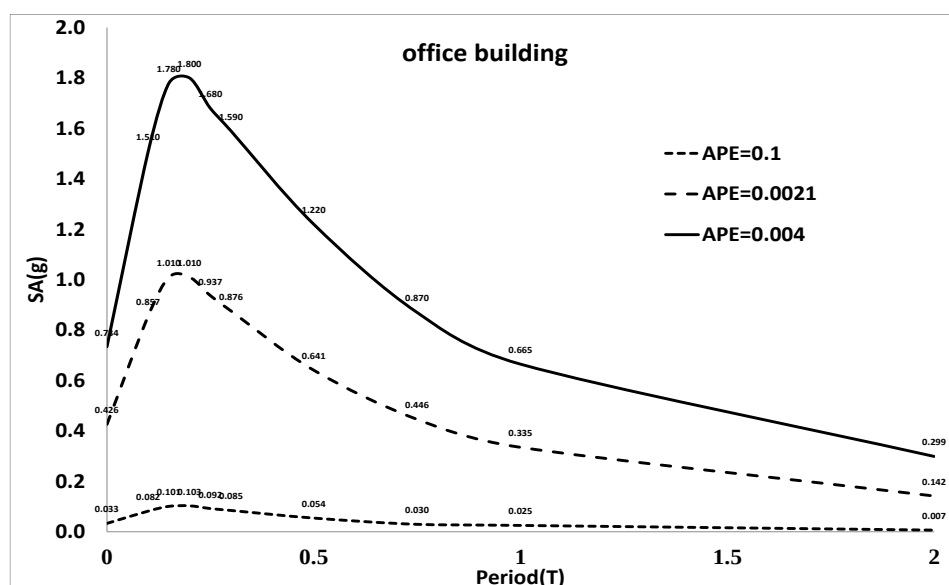


Figure 2. Uniform hazard spectra for deterministic, severe, design-level, and minor earthquakes at the building site.

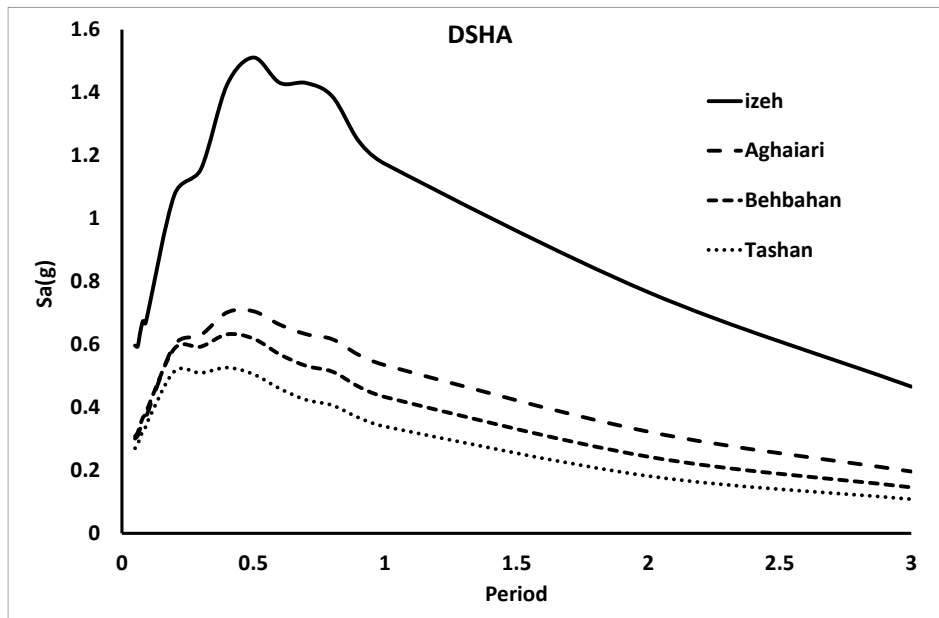


Figure 3. Uniform hazard spectrum based on the ground motion prediction equation

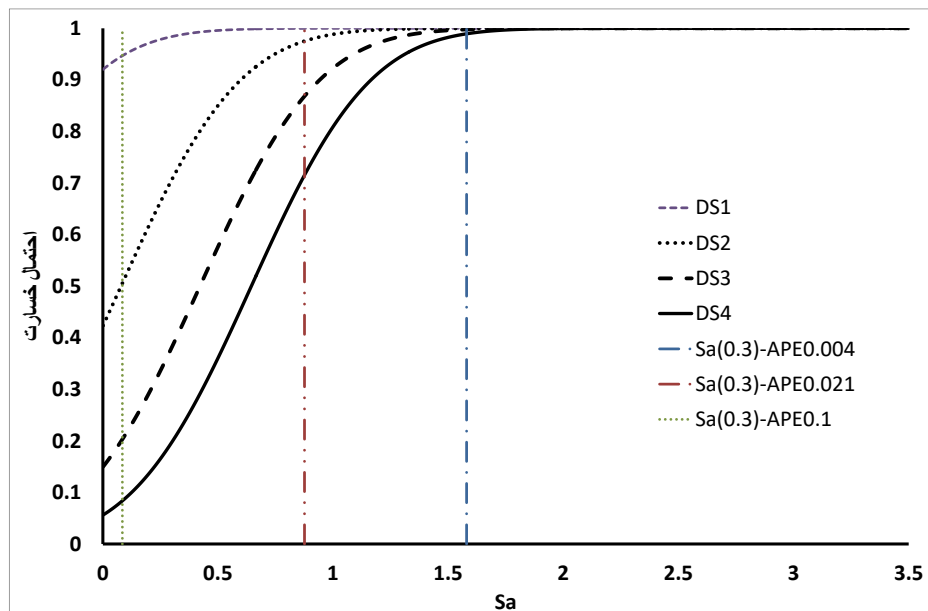


Figure 4. Fragility curves and damage levels for deterministic, severe, design, and minor earthquakes at the management building site.

Given the proximity of active faults near the site, deterministic seismic hazard analysis was conducted considering four fault activation scenarios at the shortest distances to the site. The maximum spectral acceleration reached about 1.6g, which is lower than that for the severe earthquake scenario. Most refinery buildings have fundamental vibration periods less than 0.5 seconds, so the seismic risk to these buildings can be significant.

For seismic risk analysis, three components are essential: hazard, vulnerability, and exposure. The seismic hazard for the site was detailed earlier. Vulnerability was assessed via fragility curves, shown in [Figure 3](#) [8]. From these curves, the spectral

acceleration at 0.3 seconds ($SA(0.3)$) is extracted. Based on $SA(0.3)$, the probabilities of low, moderate, extensive, and complete damage levels for the administrative building under different earthquake scenarios—deterministic, severe, design, and minor—were derived and summarized in [Table 1](#). This approach enables quantitative estimation of the building's damage probabilities and informs decision-making on risk mitigation, retrofitting, and emergency management strategies. It highlights the importance of considering local fault proximity, realistic spectral demands, and structural vulnerability in assessing seismic risk for industrial buildings like those studied here.

3. RESULTS AND DISCUSSION

The results of the seismic hazard and vulnerability assessments are presented in this section, followed by a detailed interpretation of their implications for the structural performance of the studied building. Using the probabilistic and deterministic analyses described earlier, the building's expected response under various earthquake scenarios—including minor, design-level, severe, and deterministic events—was quantified through spectral acceleration demands, fragility-based damage probabilities,

debris generation estimates, and casualty predictions. These results are discussed comparatively to highlight the influence of seismic intensity, structural configuration, and code-compliance limitations on the overall seismic risk of this old industrial reinforced concrete building.

[Table 1](#) shows Probability of exceeding various damage levels in deterministic, severe, design, and minor earthquakes for the building is .

Table 1. Probability of exceeding various damage levels

earthquake	Damage level			
	DS1	DS2	DS3	DS4
Deterministic	100	100	96	89
APE=0.0004	100	100	100	99
APE=0.0021	100	98	87	71
APE=0.1	95	50	20	8

Based on the information in [Table 1](#), the building has a high probability of damage at all levels during the deterministic earthquake. The probability of slight damage (DS1) is 100%, which means damage to non-structural components, with the building's function either preserved or immediately restorable with minor repairs [9-12]. The probability of moderate damage (DS2) is also 100%; this damage level indicates harm to structural components causing functional impairment and requiring repairs that may take several months. The probability of extensive damage (DS3) is near 100%; in this case, structural damage is significant enough to disrupt functionality and cannot be restored by routine repairs, although high casualties are not expected. The probability of complete damage (DS4) is about 90%, representing severe structural damage and total loss of function, which leads to debris spreading in the surrounding area [13]. Furthermore, the likelihood of high casualties exists in this scenario. Based on these results, it can be concluded that in the deterministic earthquake, all damage levels are probable in the building [14-17].

There is also a probability of slight damage in the building during a minor earthquake; in this case, the slight damage probability is high while other damage levels are low. The most critical earthquake to consider is the design-level event. At the design level, the probabilities of slight, moderate, extensive, and complete damage are 100%, 98%, 87%, and 71% respectively. Therefore, building performance under the design earthquake is weak and requires closer examination. Moreover, the probability of slight damage in refinery buildings during the severe earthquake is almost 100%, with a very high likelihood of moderate damage. According to these results, it can be said that in the severe earthquake, the probability of extensive and higher damage levels is very high [18-20].

Having these damage probabilities, the amount of debris and casualties can be estimated according to the Hazus methodology. For this purpose, the unit weight table of elements ([Table 2](#)) and debris generation tables ([Tables 3](#) and [4](#)) are required [21-24].

Table 2. Unit weight (in tons per 93 square meters) of structural and non-structural elements based on the specific building type (Hazardus).

Type	Reinforced concrete and steel		Brick, wood, etc.	
	structural	Non structural	structural	Non structural
S1L	44.0	5.0	0.0	5.3
S5L	45.0	4.0	20.0	5.3
C1L	98.0	4.0	0.0	5.3
C3L	90.0	4.0	20.0	5.3
URML	41.0	4.0	35.0	10.5

Table 3. Debris generated from damaged bricks, wood, and other structural and non-structural elements (as a percentage of weight) according to HAZUS

Type	Non structural damage				Structural damage			
	low	medium	extensive	full	low	medium	extensive	full
S1L	1	7	35	100	0	0	0	100
S5L	1	7	35	100	5	25	60	100
C1L	1	7	35	100	0	0	0	100
C3L	1	7	35	100	5	25	60	100
URML	2	12	45	100	5	25	55	100

Table 4. Debris generated from damaged reinforced concrete and steel structural and non-structural elements (as a percentage of weight) according to HAZUS

structure	Non structural damage				Structural damage			
	low	medium	extensive	full	low	medium	extensive	full
C1L	0	8	28	100	0	5	33	100

Based on this, the probability of debris can be calculated by multiplying the damage probability by the unit weight ([Table 2](#)) and the debris percentage ([Table 3](#) or [4](#), as applicable). The results of these calculations for different cases are as follows:

- In the deterministic earthquake, the total debris volume is approximately 109.62 tons.
- In the minor earthquake, the debris volume is estimated at about 8.09 tons.
- For the design-level earthquake, the debris is around 92.72 tons.

- For the severe earthquake, the debris volume is estimated to be 118.55 tons.

These debris estimates are instrumental for post-earthquake recovery operations, emergency planning, and risk management, allowing for a realistic assessment of the cleanup and logistic requirements according to different seismic scenarios [26-30]. This method effectively translates seismic damage probabilities into tangible outcomes crucial for industrial infrastructure resilience planning.

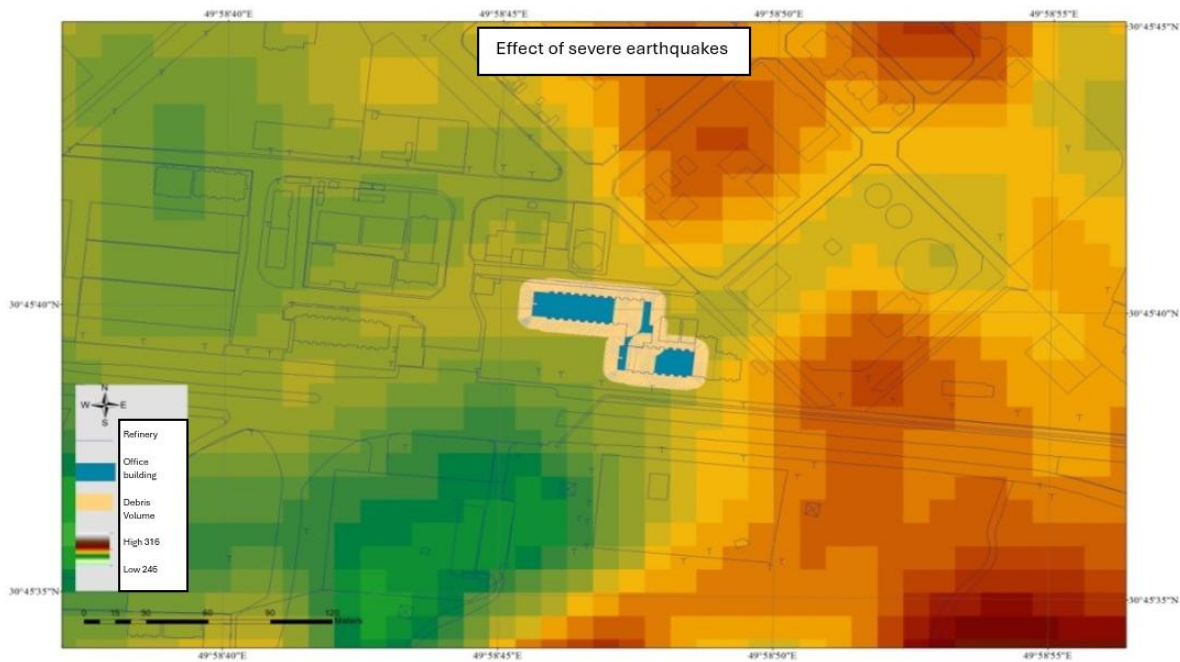


Figure 5. Effect of debris on pathways during a severe earthquake

For most building types, default values assume that out of every 100 people present in the collapsed section of a building, 10 are killed immediately (intensity level 4), and 5 others become trapped and lose their lives without rapid rescue and immediate medical attention (intensity level 3). These values are based on typical building configurations and the assumption that even with collapse, most occupants at risk can escape the structure. However, for buildings expected to experience "pancake" collapse or where occupants are buried under heavy debris, this factor of 5 may be lower, as a much larger proportion of occupants may be trapped and killed, although many at-risk occupants may survive.

4. CONCLUSION

This study analyzed seismic risk for a reinforced concrete frame building with shear walls situated in an industrial facility, constructed in the 1970s without full compliance with modern seismic codes. The investigation aimed to assess the vulnerability of this older structure to earthquakes of various intensities in order to provide a comprehensive perspective on seismic hazards and potential consequences.

The first step involved probabilistic seismic hazard analysis using uniform hazard spectra at the site, covering four earthquake levels: deterministic, minor, design, and severe, based on multiple attenuation relationships and OpenQuake software. Results showed spectral accelerations reaching approximately 1.8g for severe and 1.0g for design

earthquakes, with lower values for minor earthquakes. Deterministic analysis of four nearby faults indicated a maximum spectral acceleration near 1.6g, lower than severe earthquake intensity but still presenting significant risk given the typical short fundamental periods (under 0.5 seconds) of refinery buildings. Next, fragility curves from literature were used to estimate probabilities of slight, moderate, extensive, and complete damage. The analyzed building has an extremely high probability of exceeding all damage levels at deterministic and severe earthquakes: slight, moderate, and extensive damage probabilities approach 100%, while complete damage probability ranges from 71% to 90%. Design-level earthquakes also showed high probabilities especially for moderate to complete

earthquakes, with lower values for minor earthquakes. Deterministic analysis of four nearby faults indicated a maximum spectral acceleration near 1.6g, lower than severe earthquake intensity but still presenting significant risk given the typical short fundamental periods (under 0.5 seconds) of refinery buildings. Next, fragility curves from literature were used to estimate probabilities of slight, moderate, extensive, and complete damage. The analyzed building has an extremely high probability of exceeding all damage levels at deterministic and severe earthquakes: slight, moderate, and extensive damage probabilities approach 100%, while complete damage probability ranges from 71% to 90%. Design-level earthquakes also showed high probabilities especially for moderate to complete

damage, indicating weak building performance and the need for detailed evaluation. Further HAZUS-based calculations estimated debris volume and potential fatalities for different earthquake levels. Debris was estimated between 8 to 119 tons, which would not obstruct adjacent streets but requires careful post-earthquake crisis management planning. Human casualties ranged from less than one in minor earthquakes to about eight in severe events, highlighting significant risk in higher intensity earthquakes. Given the building's age and outdated seismic design basis, retrofitting or strengthening is clearly necessary to enhance safety. Assumptions about casualties also suggest that for buildings with potential pancake collapse or complete floor failure, fatality multipliers should be increased to more accurately model death and entrapment risks. This emphasizes the importance of considering specific failure modes in seismic risk assessments and highlights the need to tailor mitigation strategies accordingly. Additionally, the close proximity of active faults to the site underscores the potential for major earthquakes with significant impacts. The study also

stresses the importance of updated and accurate seismic hazard data through probabilistic and deterministic modeling under realistic conditions for effective safety planning in industrial units. This allows decision-makers to adopt more informed risk management policies. Ultimately, despite substantial improvements in seismic regulations in recent years, older industrial buildings designed per earlier standards remain vulnerable to major earthquake damage. Comprehensive seismic risk assessment and performance evaluation of existing industrial structures are critical not only for life and asset protection but also for safe and sustainable operation of essential facilities. Thus, these findings serve as a valuable reference for seismic retrofit planning, emergency management, and risk reduction in similar industrial buildings, advancing earthquake preparedness and mitigation efforts. It is recommended that future studies incorporate more detailed structural properties, complex dynamic behaviors, and non-structural effects to refine risk models and develop targeted strengthening strategies.

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